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Variation in macrofaunal communities of sea grass beds along a pollution gradient in Bolinao, northwestern Philippines

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ABSTRACT

This study examined the variation of macrofaunal communities in sea grass beds along a pollution gradient in Bolinao, northwestern Philippines. We established four stations and compared the diversity and abundance of macrofauna between them. The Shannon diversity index in the least polluted station was more than twice higher than that in the most polluted one. Abundance was more than thrice higher in the most polluted station. The species composition generally varied, with community difference explained largely by the predominance of the filter-feeding bivalve *Gafrarium pectinatum* and polychaete *Capitella capitata*. Species heterogeneity was reduced along the pollution gradient by approximately 19% from the least polluted to the most polluted station. This reduction indicates biodiversity alteration, which has a significant impact on ecosystem functioning. Aspects of species heterogeneity should be considered in environmental impact assessments and the management of coastal areas encountered with anthropogenic disturbances.

1. Introduction

The worldwide decline in sea grass beds due to human-induced pollution, including marine fish farming, has been previously reported (Hemminga and Duarte, 2000; Larkum et al., 2006; Waycott et al., 2009; Unsworth et al., 2014). However, as the majority of the studies have focused on the effects of pollution on sea grasses, there have been only few reports on the impact of fish farming on sea grass-associated fauna, including benthic macrofauna or macroinvertebrates (e.g., Kalantzi and Karakassis, 2006; Katavic and Antolic 1999; Dimech et al., 2002; Eklöf et al., 2005; Apostolaki et al., 2007; Papageorgiou et al., 2009). Hence, we lack valid information on mariculture-induced effects on sea grass macrofaunal communities despite their significant importance in maintaining multiple functions of sea grass ecosystems and on the sustainable use of provisioning services by sea grass beds (Cullen-Unsworth et al., 2013; Nakaoka et al., 2014; Unsworth et al., 2014; Duffy et al., 2015).

Sea grass beds are highly valuable ecosystems on Earth (Costanza et al., 1998; Moberg and Rönnbäck, 2003; Nakaoka et al., 2014) and serve as a valid example of coupled social–ecological system (Cullen-Unsworth et al., 2013; Unsworth et al., 2014). The declining status of sea grass resource, due to local- and/or global-scale environmental change, has significant effects on the resilience of the society and coupled social–ecological system (Cullen-Unsworth et al., 2014). Many macrobenthic animals, together with fish, associated with sea grass beds, such as crustaceans, mollusks, and echinoderms, have been exploited by humans for their income generation and/or food (see also Nakaoka et al., 2014). Dramatic decrease or even nonexistence of sea grass invertebrates threatens an important food and income source, resulting in negative impacts on the well-being and livelihood of the society that is dependent on sea grass fisheries (sensu Cullen-Unsworth et al., 2014). Despite their importance, sea grass beds have been experiencing unprecedented rates of loss and increasing exploitations (Duarte, 2002; Waycott et al., 2009). Considering the role of sea grass macrofaunal community in achieving environmental change is an important step to protect the society and maintain ecological resilience in sea grass system.

A qualitative description of the effects of organic pollution on benthic dynamics was described by Pearson and Rosenberg (1978): species richness declines, whereas biomass and abundance initially increase and then decrease as the pollution load increases. The predominance of opportunistic species in a polluted environment (i.e., primarily some species of polychaetes) changes the species composition of benthic communities (Warwick and Clarke, 1994). Studies involving a

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predictive analysis have highlighted the role of hypoxia in the alteration of benthic structures (e.g., Diaz and Rosenberg, 1995; Heip, 1995; Nilsson and Rosenberg, 2000; Rosenberg, 2001). Gray et al. (2002) suggested that, among the various marine fauna, fish are the most sensitive to hypoxia, whereas mollusks are the least sensitive, followed by polychaetes. Many benthic species exhibit different behaviors to a polluted environment before they eventually die (Diaz and Rosenberg, 1995), which leads to a wide variation in assemblage structures along the pollution gradient.

Univariate measures, such as the number of species, abundance, and biomass, and multivariate measures, such as species composition and similarities, are often used to describe the population and community responses to natural and/or human-induced disturbances (e.g., Warwick, 1986; Warwick et al., 1987; Tsutsumi et al., 1991; Simboura et al., 1995; Botter-Carvalho et al., 2014). While a diversity index is commonly used to analyze most field data, the index values can be converted to true diversity values or effective numbers of species, making it directly comparable to species richness (Jost, 2006, 2007). Although recent studies have considered scale dependency in the measures of community composition by partitioning the variability in diversity into alpha and beta components (Ellingsen and Gray, 2002; Okuda et al., 2004), there is little information on whether species composition varies at the within-site scale or whether such within-site variability or heterogeneity changes along environmental gradients (Ellingsen, 2001; Ellingsen, 2002; Becking et al., 2006; Lohrer et al., 2013). Understanding several aspects of macrobenthic community structures based on field data may lead to more informed management decisions regarding pollution-related environmental concerns.

The aim of this study was to investigate the variation in community structure of macrobenthic invertebrates in sea grass beds along a pollution gradient. The study was conducted in a mariculture-impacted area of Bolinao, northwestern Philippines, with four sampling stations established along a known gradient of dissolved nutrients and chlorophyll-a concentrations. Our general hypothesis was that the macrofaunal community structures would be negatively altered; in particular, species diversity and abundance of macrofauna would be suppressed toward the polluted stations. We also hypothesized that the community assemblages would vary across stations. The likely predominance of some opportunistic species and species tolerance to pollution were also expected in the stations. Finally, we hypothesized that the species heterogeneity (i.e., variation in species composition among samples within a given area) would be reduced toward polluted stations.

2. Materials and methods

2.1. Study area

The study was conducted in September 2010 and March 2011 in Bolinao, northwestern Philippines (Fig. 1). The area has the most extensive reef system in the northwestern part of the country (Mcmannus et al., 1992), with approximately 22,500 ha of sea grass coverage. The unregulated establishment of milkfish (*Chanos chanos*)-farming pens and cages on its shallow coastal waters since 1995 has dramatically produced negative effects in water and sediment qualities (Holmer et al., 2002; Holmer et al., 2003; San Diego-McGlone et al., 2008; Santander et al., 2008; David et al., 2009) such as fish kills and occurrences of harmful algal blooms (Yap et al., 2004; Azanza et al., 2005; Escobar et al., 2013). The environmental condition in this poorly flushed area remains serious (sensu Ferrera et al. unpublished).

Four stations located along the subtidal zone, with a sampling depth of 0.5–1.0 m (near the low-tide watermark), were established in the study area (Fig. 1). All these stations were located in the eastern reef flat of Santiago Island, the largest island of Bolinao, which is separated from the mainland by a deep channel. Station 1 was the closest to mariculture areas (i.e., <1 km away from the fish pens and cages). Station 2 was located <2 km northeast of station 1, station 3 was <4 km north of station 2, and station 4 was located <4 km northwest of station 3 within the Bolinao sea grass reserve. As a point of reference, we considered stations 1 and 4 as the most and least polluted stations, respectively (Watai et al., 2015). The silt–clay component of the sediment near the sampling stations, before mariculture was fully established in Bolinao, did not show a huge difference (Fig. 1, 6.7–9.8%, Terrados et al., 1998). The range was found to be much lower than that in the south of the channel between Santiago Island and the mainland (27.4%).

A short-term temporal survey on these sampling stations regarding the dissolved nutrients and chlorophyll-a concentrations (Table 1, Fortes et al., 2012) showed some variation in the water quality parameters between them (Ashikawa et al., 2008 in Watai et al., 2015). In addition, hydrodynamic simulation by the members of our research group in the "Coastal Ecosystem Conservation and Adaptive Management under Local and Global Environmental Impacts in the Philippines (CECAM)" project showed a monotonic decline in nitrogen load from the most polluted station (1) to the less polluted station (4) (Nadaoka, 2015). Other colleagues of the project, Ferrera et al. (unpublished), whose study locations were close to our sampling stations, reported that Bolinao coastal waters remained eutrophic, with high dissolved inorganic phosphate (up to 4 μM during the dry season) being exacerbated by the increase in fish farm structures.

Tanaka et al. (2014) reported that the mariculture-induced pollution negatively alters the composition and/or richness of the species of the sea grass vegetation in Bolinao. Within our sampling stations, the species richness starts from at least two species at station 1 (*Enhalus acoroides* and *Thalassia hemprichii*) to seven species at station 4 (*E. acoroides*, *T. hemprichii*, *Halophila ovalis*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Halodule uninervis*, and *Syringodium isoetifolium*) Fortes et al. (2012). On the contrary, the difference in gleaning/fishing access across some stations could possibly influence the variation of macrofaunal community structure. The sea grass beds in stations 1–3 can be freely gleaned by coastal villagers, whereas those in station 4 were not (as it is located within the sea grass sanctuary). This and other possible confounding factors were beyond the scope of this study.

2.2. Sample collection and laboratory work

Macrofauna were collected by sediment coring to a depth of 10 cm (2010: $n = 10$, 2011: $n = 5$). The aluminum core had an inner diameter of 20 cm, resulting in a surface area of 0.03 m^2 per core sample. The samples were haphazardly sampled within approximately 50-m diameter of sea grass bed at each station (i.e., the same area used by Fortes et al., 2012). A sieve with a 1.0-mm mesh opening was used to partially sieve core samples in the field, thereby removing unwanted items such as stones, sand, and debris.

The collected samples were placed in prelabeled sample bags and then brought to the laboratory after each sampling period for processing. In the laboratory, the core samples were cleaned using seawater, and the macrofaunal individuals were collected and sorted to the lowest taxonomic level, where possible, using taxonomic references for polychaetes (Fauchald, 1977; Fauchald and Jumars, 1979), mollusks (Hinton, 1975; Okutani, 2000), echinoderms (Schoppe, 2000), and a general updated taxonomy of all marine fauna (WoRMS Editorial Board, 2015). The count for each species per core sample was also recorded. Macrofaunal samples were preserved with 70% ethanol.

2.3. Data analyses

Majority of the results of our univariate and multivariate analyses did not show variation across sampling time/period. Our data set then composed of 15 replicate samples per station and all proceeding statistical analyses were compared between stations.